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DETERMINATION OF CERTAIN CHARACTERISTICS OF SOIL ACCORDING TO MICROWAVE RADIATION DATA

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16. Abstract

A method is described whereby it is possible to determine soil humidity, surface temperature gradient, surface reflection coefficient and exponential temperature profile factor on the basis of the measured amplitudes of the zero and first harmonics of the radio brightness temperature.

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DETERMINATION OF CERTAIN CHARACTERISTICS OF SOIL ACCORDING TO MICROWAVE RADIATION DATA

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An expression was derived [1] for the radio brightness temperature of the thermal radiation of the surface layer of soil, measured at the earth's surface; the contribution of backscattered atmospheric radiation, which is negligible in the microwave band, was ignored. The calculations were done [1] in approximation of a soil absorption coefficient that is constant with depth (α = const) and for a set of temperature profiles T(z) with a possible maximum or minimum, gradually changing to a constant asymptotic value at sufficiently great depths. It should be pointed out that this set of profiles embraces practically all the varieties that are observed in the surface soil layer [2]. /88*

In the wavelength band for which $\gamma/\alpha \ll 1$ (γ is the empirical parameter of the temperature profile that characterizes the exponential temperature drop at great depths), the radio brightness temperature may be written in the form

$$T_b = [1 - R(\theta)^2]\left[T_0 + \frac{T'(0)\cos\theta}{\alpha}\left(1 - 2\frac{\gamma\cos\theta}{\alpha}\right)\right], \qquad (1)$$

where $R(\theta)$ is the reflection coefficient, T_0 is the temperature for which $z = 0$, $T'(0)$ is the surface temperature gradient, and θ is the angle of sight (relative to the vertical).

A method of determining (for known T_0) soil humidity w and R, α and the temperature profile parameters $T'(0)$ and γ that depend on it, through measurements of brightness temperature on several wavelengths is described in [1]. The terms that depend on the profile parameters $T'(0)$ and γ contribute only a few degrees to T_b. For $|T'(0)| = 700°/\mathrm{m}$, $\gamma/\alpha = 0.2$, $\alpha = 100$ 1/m, for example, the correction factor for T_0 is approximately 4°. Although this contribution falls outside the range of measurement errors, it is too small in comparison with temperature T_0, which is of the order of 300°. Therefore it would be

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*Numbers in the margin indicate pagination in the foreign text.

desirable for measurements to exclude the given surface temperature T_0 and to use values that depend on the desired temperature profile parameters and soil characteristics. For this purpose it is helpful to assign to the part of T_b of interest to us certain special properties in comparison with T_0 so that the contribution of T_0 can be excluded in the special measuring method.

Such a property may be oscillation of angle $\theta = \theta_0 + \theta_1 \cos \Omega t$ in time as a result of plane oscillation of the antenna near the position of equilibrium θ_0 with amplitude θ_1. As a result of this the received signal T_b is also a periodic function of time. Harmonic analysis of this signal, presented below, shows that the amplitude of its first Fourier harmonic is not a function of T_0. This makes it possible to use as the method of measuring a signal, its detection on frequency Ω and to determine according to the amplitude of the first harmonic the temperature profile parameters and soil characteristics. This approach, naturally, presumes that the soil has horizontal homogeneity.

If angle θ oscillates in time at frequency Ω, T_b may be written as the Fourier series /89

$$T_b(\cos \Omega t) = T_b^{(0)} + T_b^{(1)} \cos \Omega t + T_b^{(2)} \cos 2\Omega t + \ldots$$

The constant component $T_b^{(0)}$ and the amplitude of the first harmonic can be computed with the equations

$$T_b^{(0)} = \frac{2}{T} \int_0^{T/2} T_b(\Omega t)\,dt; \tag{2}$$

$$T_b^{(1)} = \frac{4}{T} \int_0^{T/2} T_b(\Omega t) \cos \Omega t\,dt, \tag{3}$$

where

$$T_b(\Omega t) = [1 - R^2(\Omega t)]\left[T_0 + \frac{T'(0)}{\alpha} \cos[\theta_0 + \theta_1 \cos \Omega t] \cdot \left(1 - 2\frac{\gamma}{\alpha} \cos[\theta_0 + \theta_1 \cos \Omega t]\right)\right]. \tag{4}$$

We will make use of the fact that in a sufficiently wide range of angles $(0 < \theta \lessapprox \pi/4)$ the reflection coefficient $R(\theta)$ may be assumed not to depend on angle θ [3]. This enables us to perform integration in (2) and (3), which yields the following expressions for the constant component and amplitude of the first harmonic

$$T_b^{(1)} = -2(1-R^2)\frac{T'(0)}{\alpha}\left[\sin\theta_0 \cdot J_1(\theta_1) - \frac{\gamma}{\alpha}\sin 2\theta_0 \cdot J_1(2\theta_1)\right]; \tag{5}$$

$$T_b^{(0)} = (1-R^2)\left[T_0 + \frac{T'(0)}{\alpha}\cos\theta_0 \cdot J_0(\theta_1) - \frac{\gamma}{\alpha}\frac{T'(0)}{\alpha}[1+\cos 2\theta_0 \cdot J_0(2\theta_1)]\right], \tag{6}$$

where $J_0(x)$ and $J_1(x)$ are Bessel functions.

The corrections for T_0, as was mentioned above, amount to not more than 2-3% of its magnitude, and therefore equation (6) may be written in the form

$$T_b^{(0)} \approx (1-R^2)\,T_0. \tag{7}$$

We can now show that by measuring the constant component and amplitude of the first harmonic of the radio brightness temperature on three wavelengths, for which the condition $\gamma/\alpha \ll 1$ is valid, it is possible to determine humidity w, temperature profile parameters $T'(0)$ and γ and absorption characteristics α, R.

Having equation system (5) for three wavelengths and solving it in terms of the absorption coefficients, we arrive at the equation

$$\alpha_3^2 k_{12}(\alpha_1 - \alpha_2) + \alpha_2^2 k_{13}(\alpha_3 - \alpha_1) + \alpha_1^2 k_{12} k_{13}(\alpha_2 - \alpha_3) = 0, \tag{8}$$

where

$$k_{1i} = \frac{T_{b1}^{(1)}}{T_{bi}^{(1)}}\frac{(1-R_i^2)}{(1-R_1^2)}, \quad i = 2, 3,$$

or, by using equation (7),

$$k_{1i} = \frac{T_{b1}^{(1)}}{T_{bi}^{(1)}}\frac{T_{bi}^{(0)}}{T_{b1}^{(0)}}, \quad i = 2, 3.$$

By measuring the ratios of the corresponding harmonics on different wavelengths and using the dependence of α_i on humidity $\alpha_i = \alpha_i(w)$ [4], we determine from equation [8] humidity w and then the absorption coefficients themselves. The intermediate equations which contain the values k_{1i} and γ enable us to compute γ. It is noteworthy that these values are determined as a result of measurements of the harmonic ratios, which can be performed, in particular, when $\theta_0 = 0$. The harmonic ratios can be measured with greater accuracy than the harmonics themselves, which are of the order of a few degrees. Then, by measuring the harmonics $T_b^{(0)}$ and $T_b^{(1)}$ themselves, it is possible to determine from equations (7) and (5) the values R and $T'(0)$. /90

Thus, on the basis of the measured amplitudes of the zero and first harmonics of the radio brightness temperature for three wavelengths, for which $\gamma/\alpha \ll 1$, when T_0 is assigned (this value may be found on the basis of infrared measurements), and on the basis of the function $\alpha_i = \alpha_i(w)$ on these wavelengths, it is possible to determine the soil humidity and surface temperature gradient, surface reflection coefficient and the exponential temperature profile factor. The asymptotic temperature at the corresponding depth can be determined on the basis of data of radio brightness temperature measurements on wavelengths for which $\gamma/\alpha \gg 1$ [1].

The examined differential method of determining surface soil characteristics has advantages over the method proposed previously [1], since only the values that contain unknown temperature profile parameters are measured, and this increases the accuracy of determination of the latter.

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